New Approaches to Beam Design

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for the Beam Interface Group

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Outline

Long Baseline Oscillation Physics Requirements for DUNE

The primary requirements are:

- **CPV 3 sigma over 75% - this comes from P5. Currently we reach this goal with 850 kt*MW*yr with the LBNF optimized design.**
- **Explicit demonstration of CP violation and precision measurement of δ_{CP}. An unwritten goal is getting to CKM precision on δ_{CP} (< 10 degrees).**
- **Precision measurement of oscillation parameters including θ_{13} and unambiguous detemination of the MH and the θ_{23} octant. In DUNE we aim for reactor level precision on θ_{13} as a unitarity test**

Global Science Requirements of the Beam

From DocDB 112, DUNE/LBNF's formal requirement document:

Glo-Sci-13 **The neutrino beam spectrum shall cover the energy region of the first two oscillation maxima affected by muon-neutrino conversion from the atmospheric parameters.**

Glo-sci-60 **The neutrino beam spectrum shall extend beyond the first maximum to higher energies, while maintaining a high signal to background ratio to obtain the maximum number of charged current signal events. [We have not specified what range of energies...!!]**

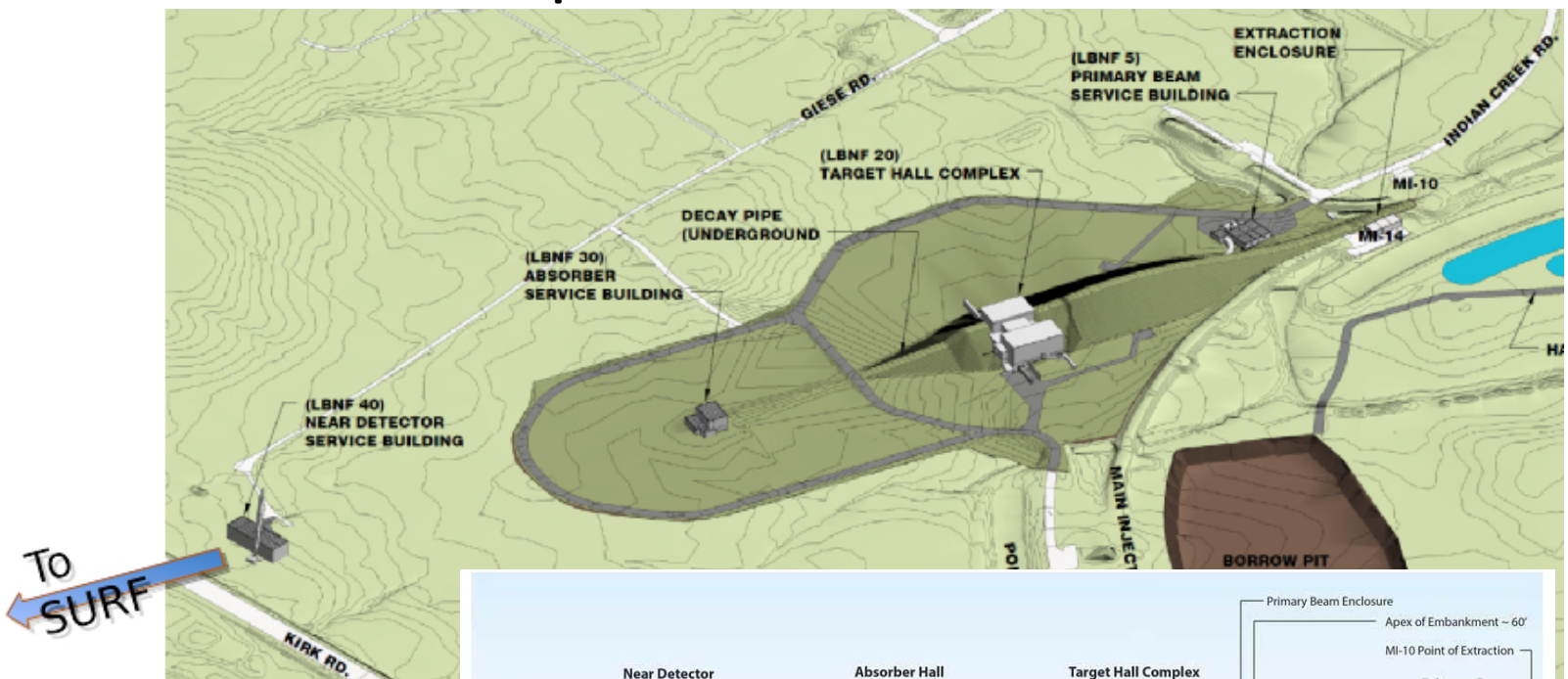
Glo-Sci-14 **The neutrino beam spectrum shall be tunable so that beam with both lower peak energy (below the first oscillation node) and higher peak energy (significantly higher than the first oscillation node) can be achieved without substantial downtime that reduces the overall exposure.**

Glo-Sci-15 **The electron neutrino content in the beam shall be kept small so that the systematic errors on the additional background has a small impact on the CP phase measurement (compared to the statistical error).**

Glo-Sci-16 **The beam shall be sign-selected to provide separate neutrino and anti-neutrino beams with high purity .....**

The LBNF Beamline

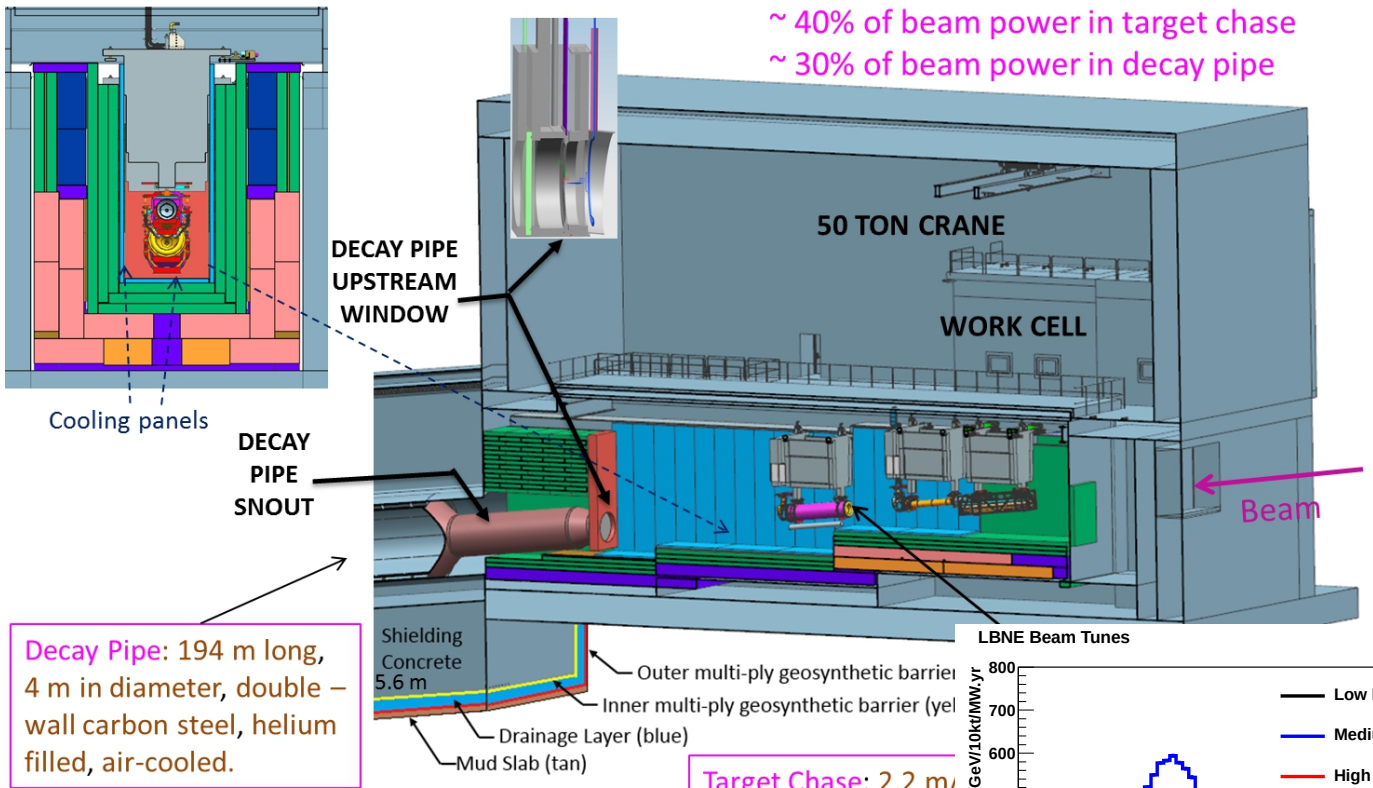
Novel concept beam-on-a-hill reduces cost.

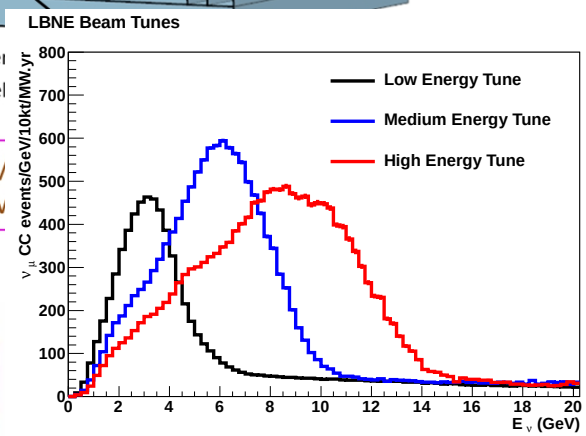


Primary proton beamline: extracts 60-120 GeV designed for 1.2MW upgradable to 2.3MW

The LBNF Beamline

Advanced conceptual design with upgraded tunable NuMI focusing:

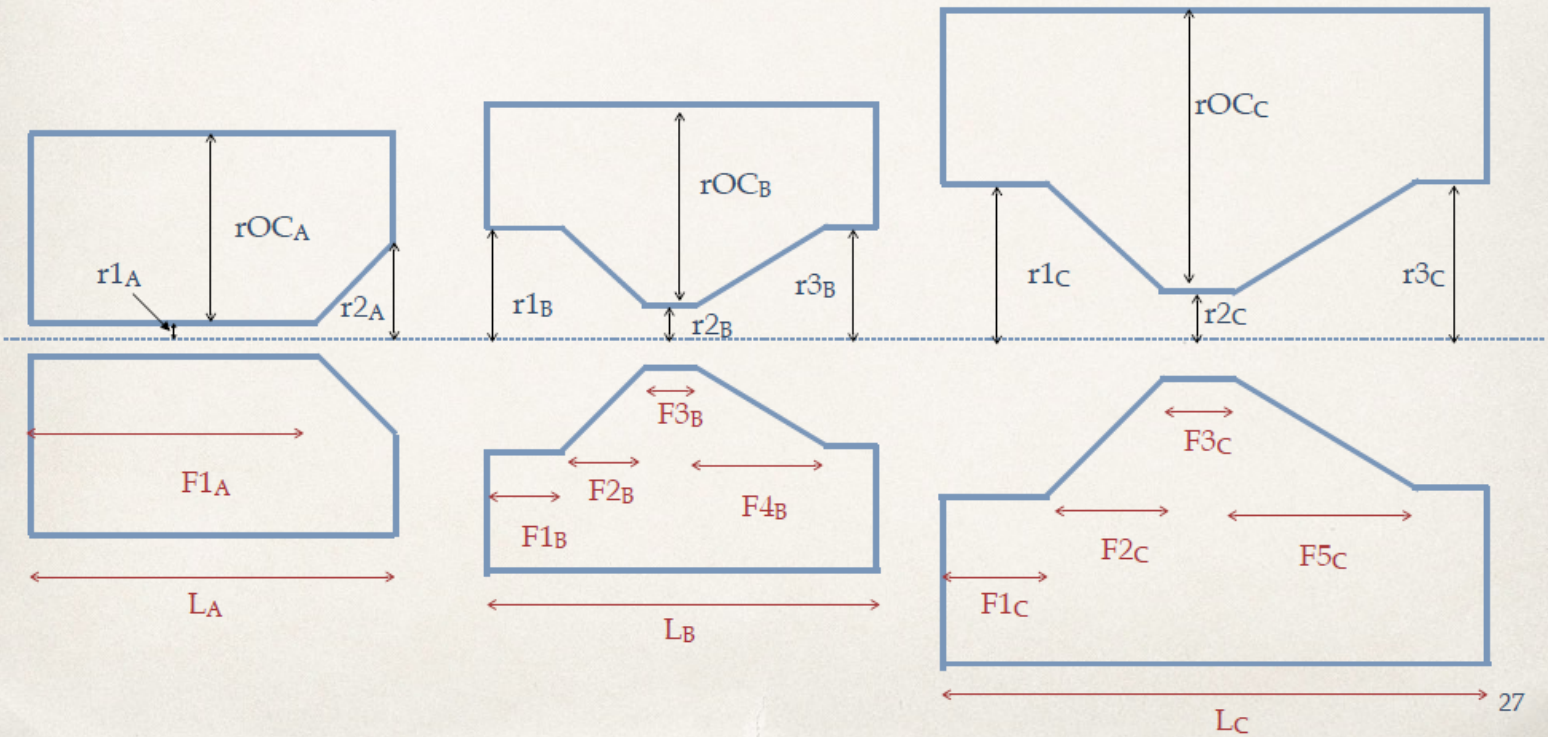




Optimization of Focusing System Geometry for CPV

Laura Fields

Horn Parameters



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Optimization of Focusing System Geometry for CPV

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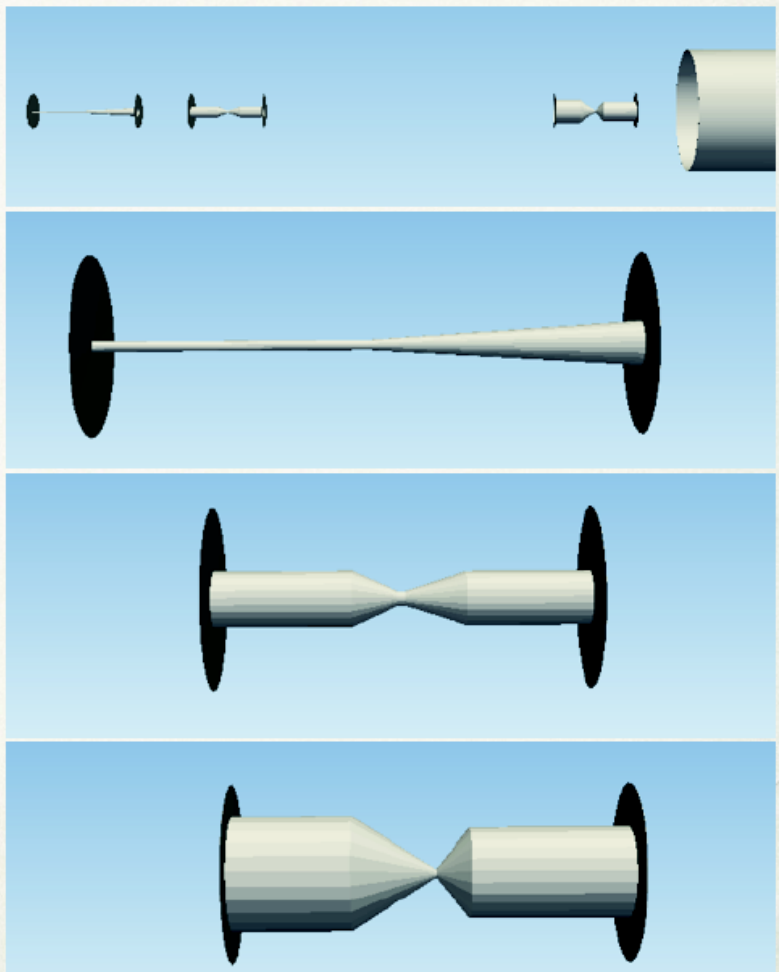
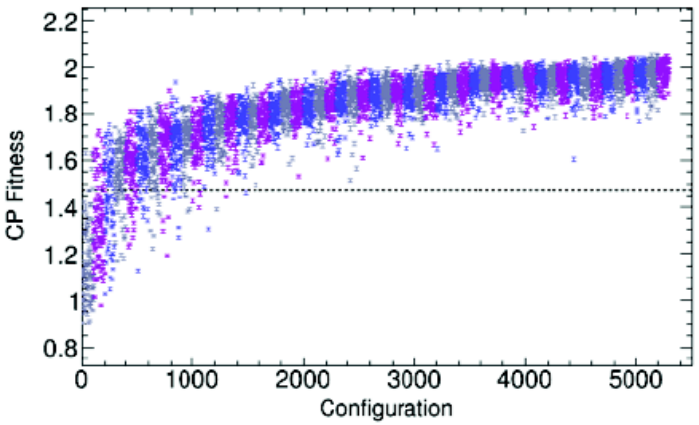
Cylindrical Target Optimization Results

Parameter	Lower Limit	Upper Limit	Unit	
Horn A: L_A	1000	4500	mm	3717
Horn A: $F1_A$	1	99	%	51
Horn A: $r1_A$	20	50	mm	33
Horn A: $r2_A$	20	200	mm	147
Horn A rOC_A	200	650	mm	630
Horn B: L_B	2000	4500	mm	2551
Horn B: $F1_B$	0	100	%	37
Horn B: $F2_B$	0	100	%	12
Horn B: $F3_B$	0	100	%	2
Horn B: $F4_B$	0	100	%	16
Horn B: $R1_B$	50	200	mm	186
Horn B: $R2_B$	20	50	mm	47
Horn B: $R3_B$	50	200	mm	179
Horn B: ROC_B	200	650	mm	633
HornB: Z position	2000	17000	mm	5453
Horn C: L_C	2000	4500	mm	2694
Horn C: $F1_C$	0	100	%	30
Horn C: $F2_C$	0	100	%	21
Horn C: $F3_C$	0	100	%	2
Horn C: $F4_C$	0	100	%	9
Horn C: $R1_C$	50	550	mm	388
Horn C: $R2_C$	20	50	mm	26
Horn C: $R3_C$	50	550	mm	306
Horn C: ROC_C	550	650	mm	620
Horn C: Z Position	4000	19000	mm	17836
Target Length	0.5	2.0	m	1.98
Beam spot size	1.6	2.5	mm	2.1
Target Radius	9	15	mm	7.8
Proton Energy	60	120	GeV	108
Horn Current	150	300	kA	270



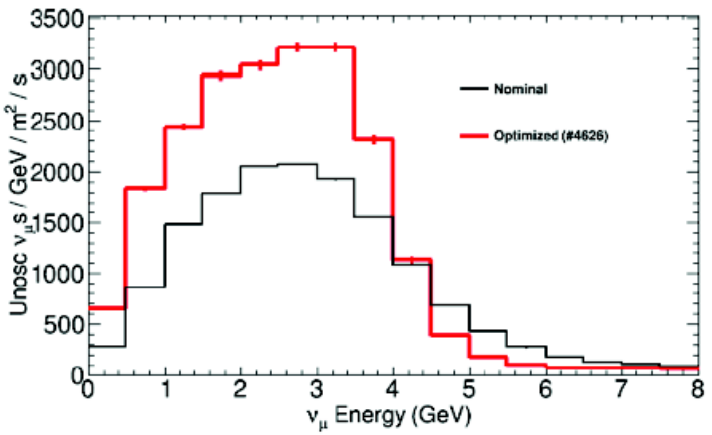
Optimization w/ Spherical Target

- Current status of optimization:



We wanted to include this optimization in the BOTF Interim Report (first draft finished and will be available soon), so I took a snapshot at a slightly earlier point in the optimization (seen here, and discussed more on following pages)

Best Fitness is 2.05
(Reference beam is 1.47)

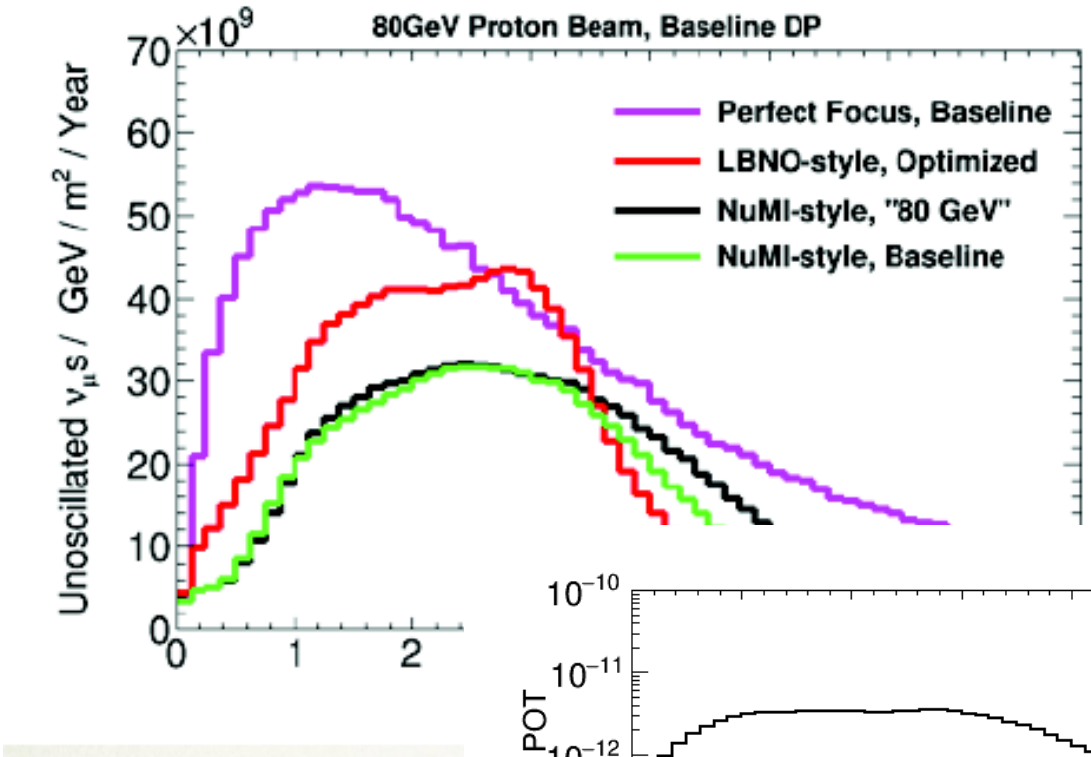


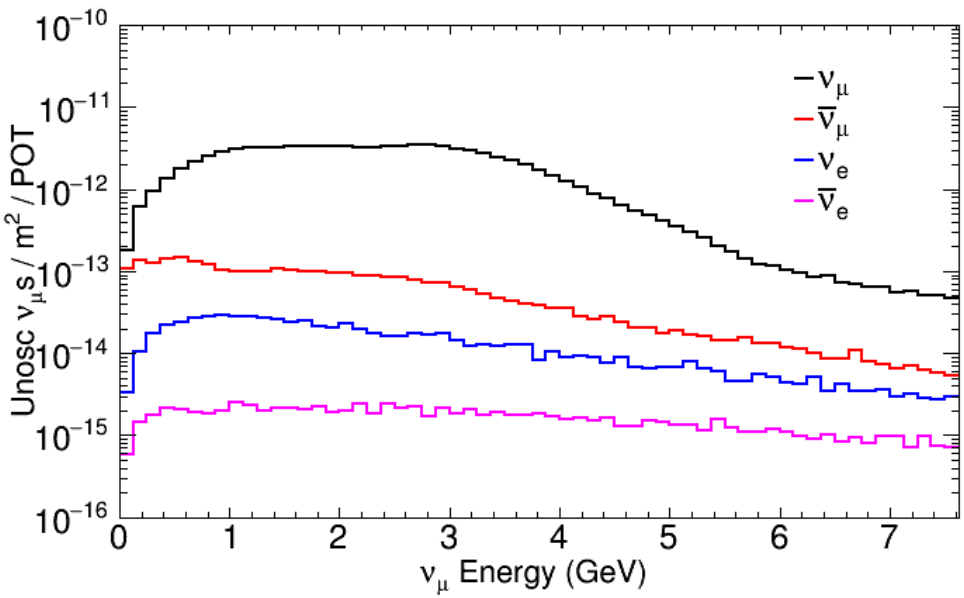
Optimization of Focusing System Geometry for CPV

Laura Fields

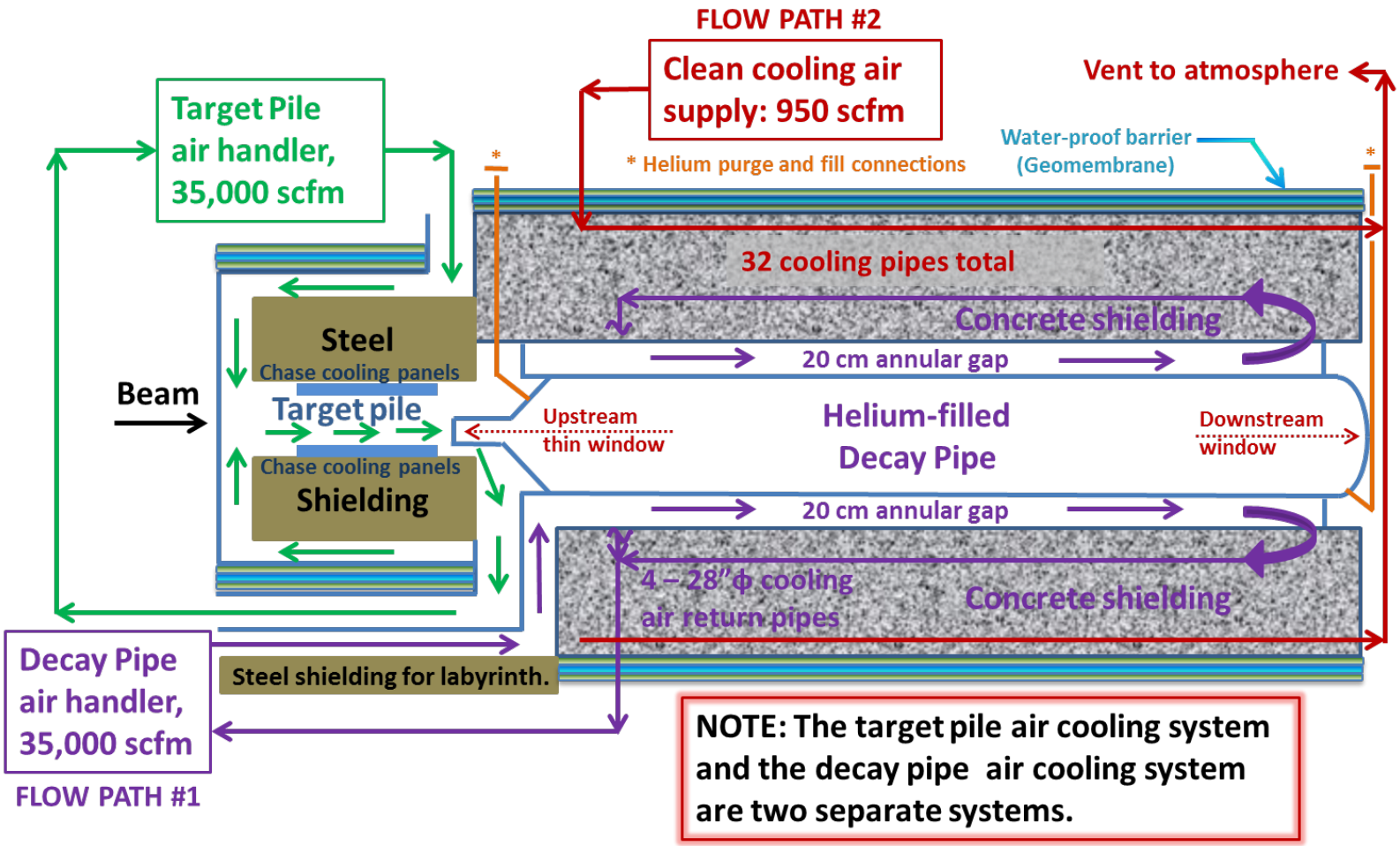
The optimized horn design for CPV is not tunable ! BUT the target chase, horn carrier systems, strip lines ...etc could be designed to allow for flexibility in deploying either the tunable NuMI focusing system or the CPV optimized focusing system. LBPWG has to be explicit about requesting this from the LBNF design team. Tunable focusing is a requirement!.

Performance of Optimized Horn Focus





LBNF Decay Pipe

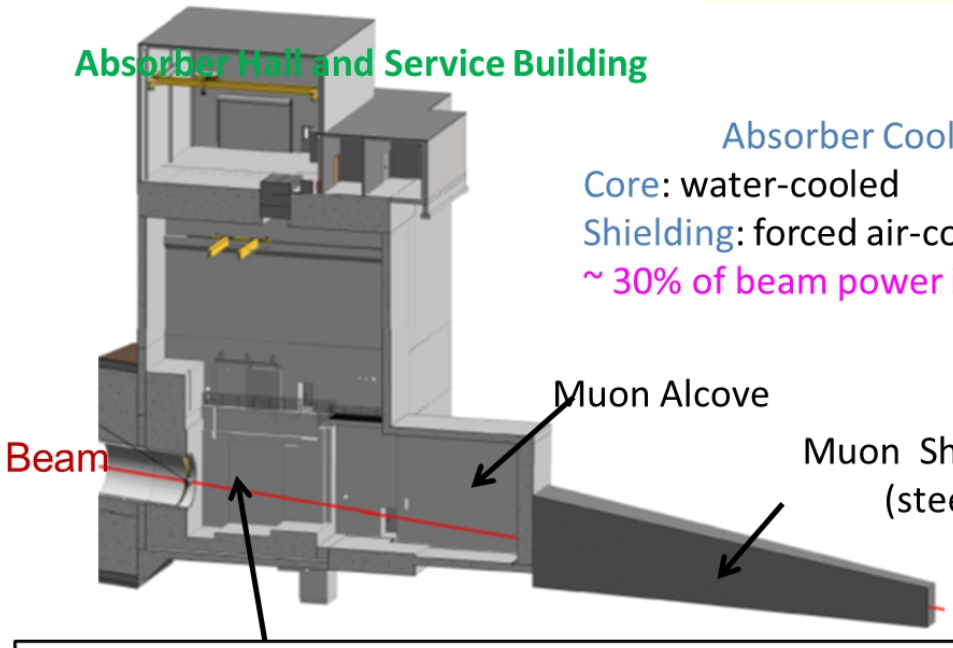


LBNF Absorber

Hadron Absorber

The Absorber is designed for 2.4 MW

Absorber Hall and Service Building



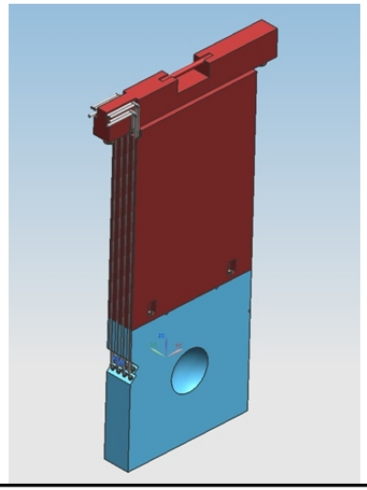
Absorber Cooling

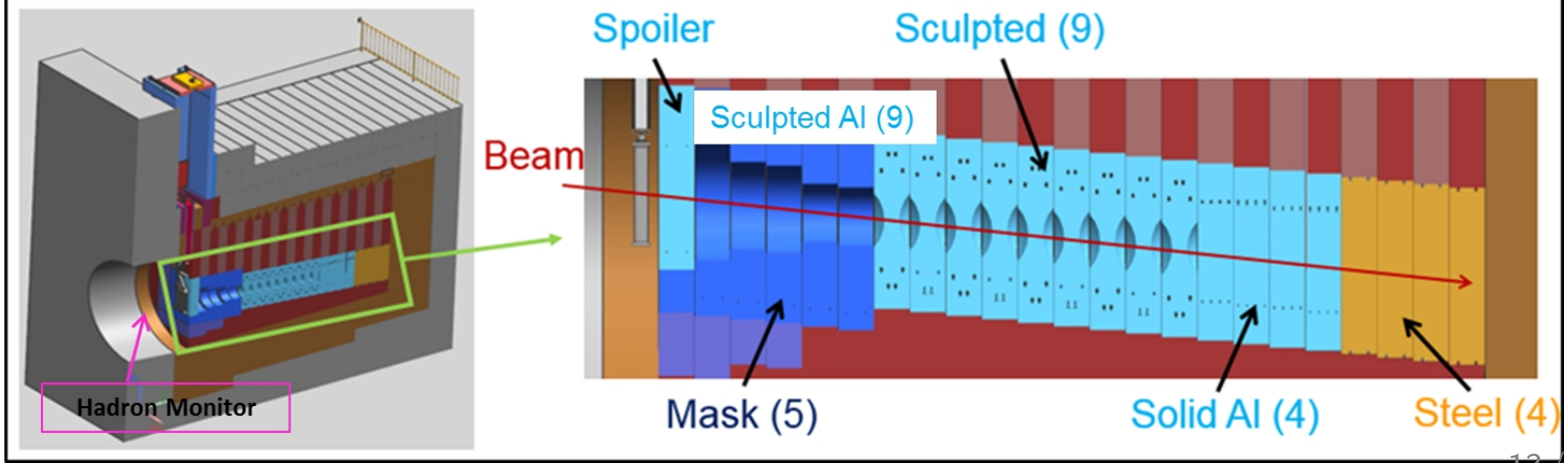
Core: water-cooled

Shielding: forced air-cooled

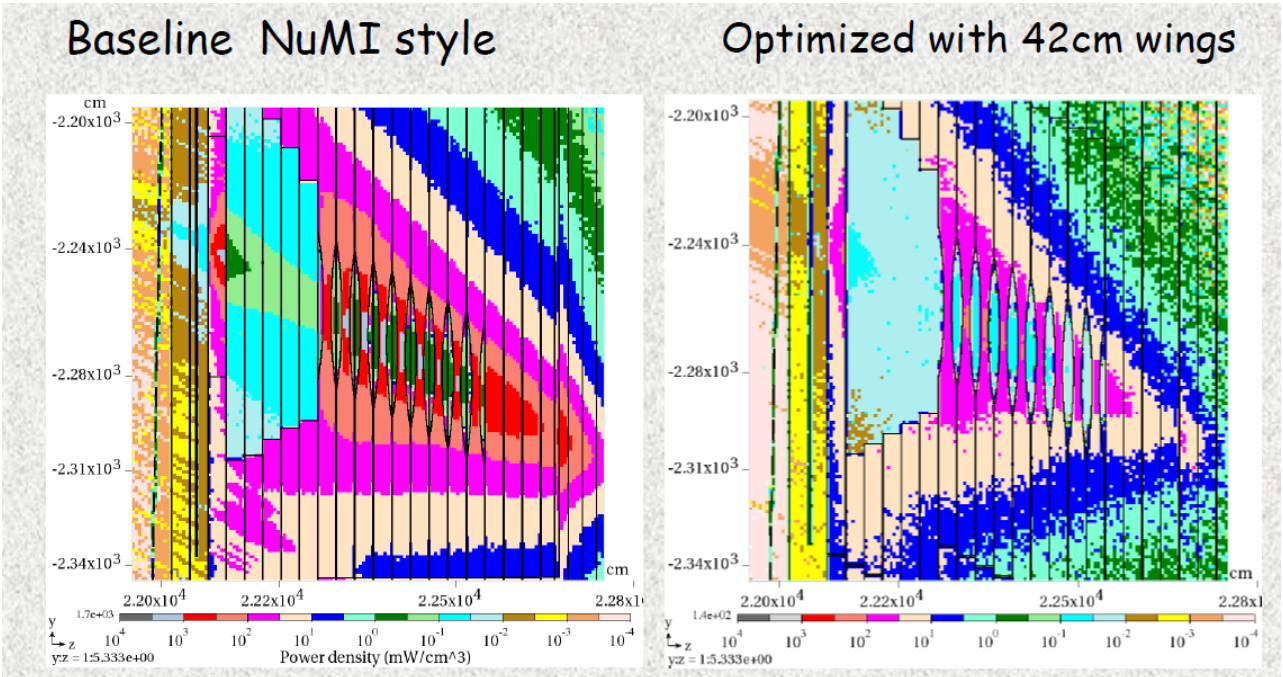
~ 30% of beam power in Absorber

Core blocks replaceable
(each 1 ft thick)





LBNF Absorber Energy Deposition

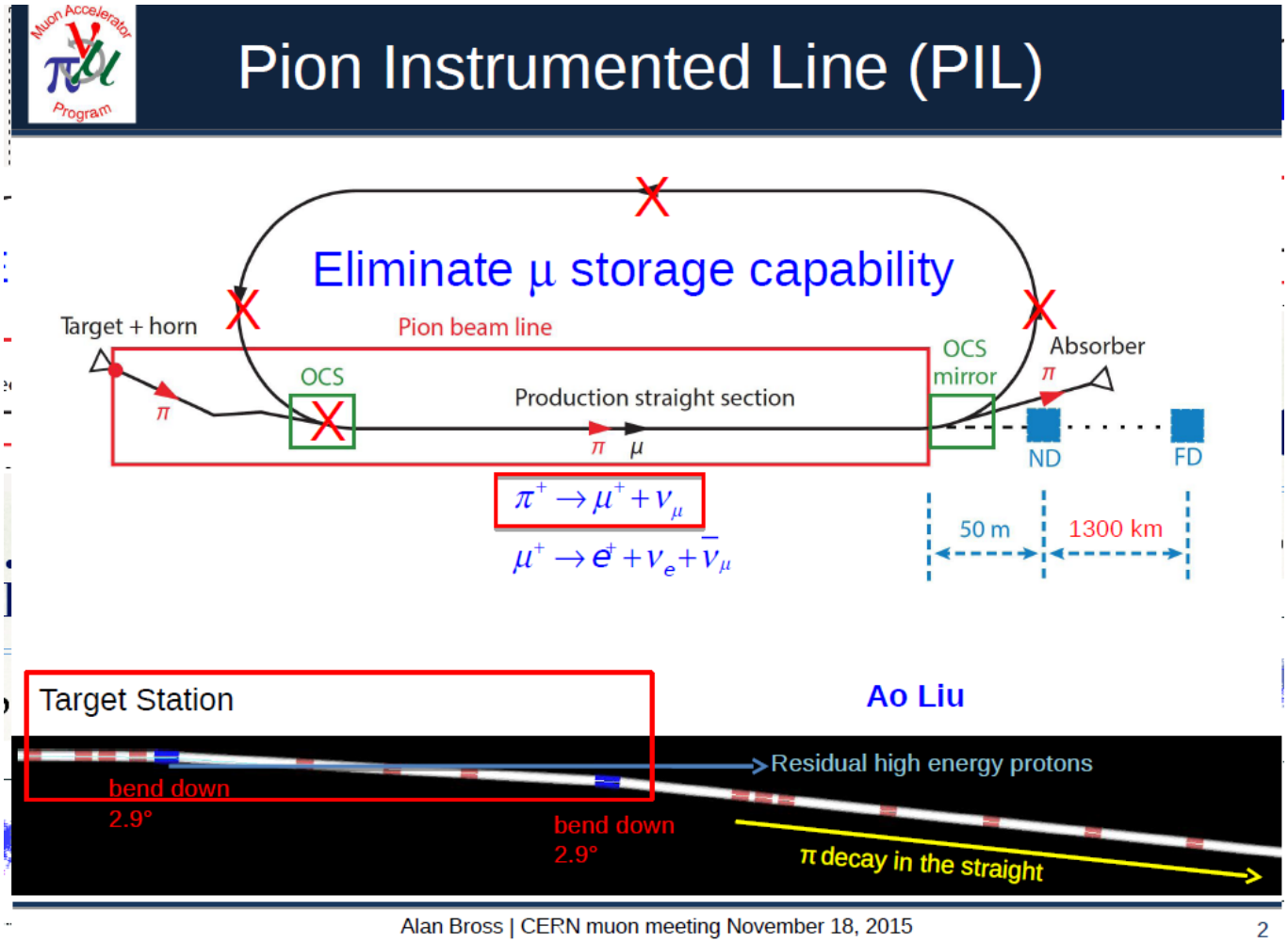


PRELIMINARY: Optimized focusing design and possible wings added to target could reduce peak energy deposition in absorber 8-12 $\times$.

If we require the beamline to accomodate the higher energy tunable NuMI systeam, the absorber design remains challenging and costly.

NuPIL: A completely new design proposal for the LBNF Beam

Alan Bross



Concept evolved from the extensive work on NuSTORM, the short baseline ν oscillation program using a μ storage ring

NuPIL: A completely new design proposal for the LBNF Beam

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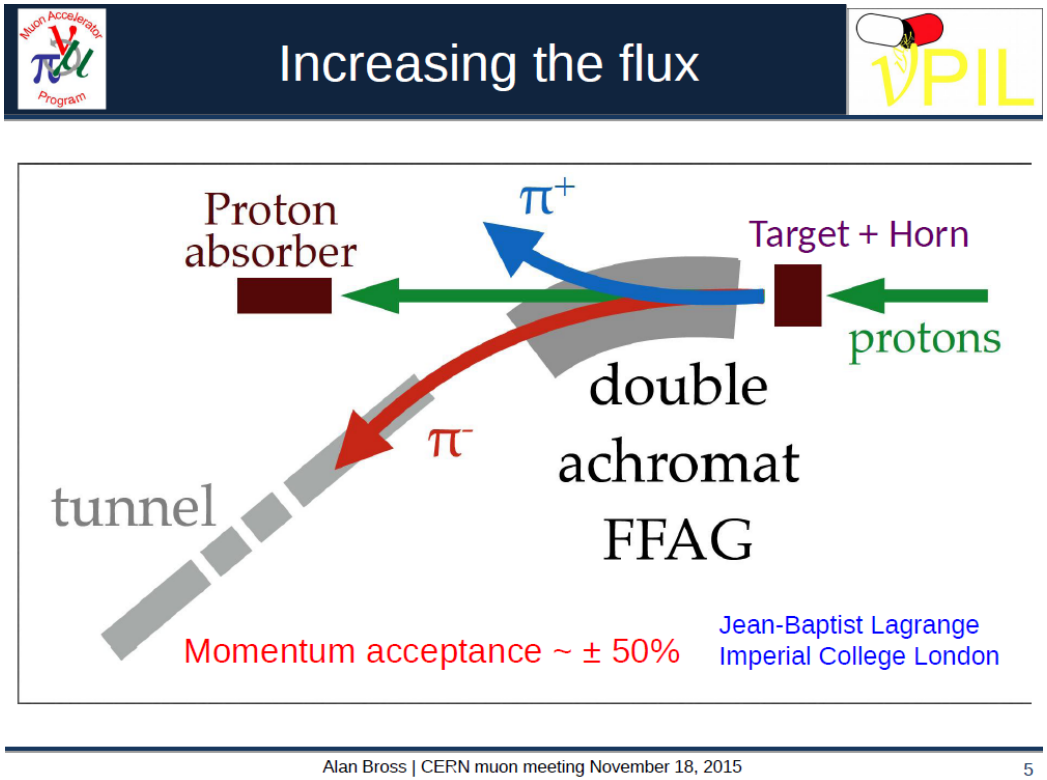

A Fixed Field Alternating Gradient (FFAG) bending magnet following a horn system provides a wider band of pion momentum acceptance. There is no hill needed and the majority of the beam power is deposited on the surface. A pion transport line after the FFAG focuses the pions in the decay tunnel. Shielding requirements for the tunnel are much less.

NuPIL: A completely new design proposal for the LBNF Beam

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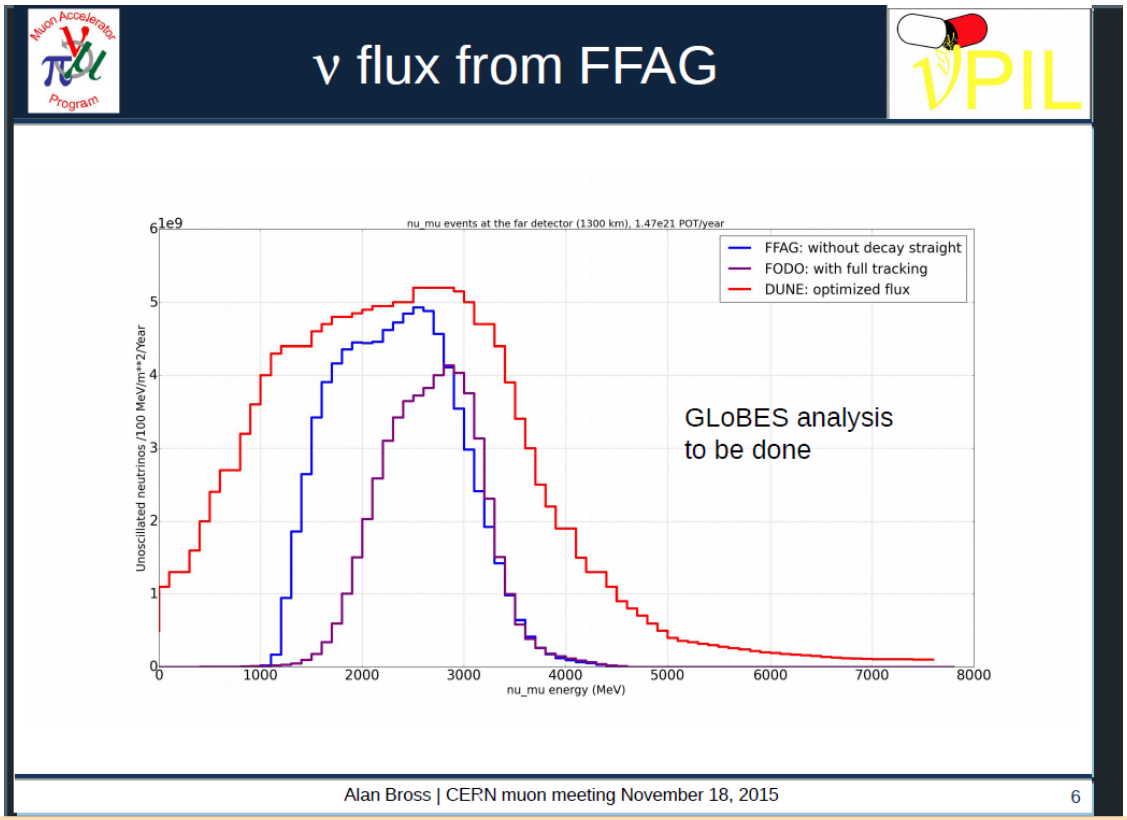

The spectrum is narrow band. No high energy tails, practically no wrong sign contamination. Magnets can be tuned to select lower energy spectrum, but higher energy spectra will be much harder to reach without changing the lattice.

Homework for LBPWG

- **The LBPWG needs to better specify the requirements for the higher energy beam tunes and the physics that enables.**
- **The LBPWG needs to examine the NuPIL design and determine whether it meets the PHYSICS requirements of LBNF/DUNE.**
- **Technical design issues will be discussed with LBNF in the DUNE Beam Interface Group (BIG ?).**
- **A plenary presentation on NuPIL is scheduled for the May Collaboration meeting.**
- **Alternative work on pion transport lines that fit within the current beamline is also being carried by Milorad Popovic in the DUNE BIG.**